COMMONWEALTH OF KENTUCKY

BEFORE THE PUBLIC SERVICE COMMISSION

*   *   *   *   *

In the Matter of:

REQUEST BY SOUTH KENTUCKY R.E.C.C. FOR PERMISSION TO ADOPT A SAMPLE METER TEST PLAN	)	CASE NO. 8536

O R D E R

South Kentucky Rural Electric Cooperative ("South Kentucky") by letter received May 24, 1982, applied for permission to institute a sample meter testing plan for single phase electric meters in lieu of the periodic meter tests required by the Commission's regulation 807 KAR 5:041, Section 15. South Kentucky filed its sample meter testing plan with its original request and filed additional information on August 6, 1982, in response to a staff request which was made following an on-site inspection of its meter testing facilities.

The Public Service Commission, after consideration of the request and all evidence of record and being advised, is of the opinion and finds that:

1. The Commission's regulation, 807 KAR 5:041, Section 16, permits a utility desiring to adopt a sample meter testing plan to submit its application to the Commission for approval.

2. South Kentucky will realize significant savings in meter test expense if sample meter testing is adopted. The estimated number of meters that would be tested if the existing

periodic testing plan were continued in 1983 would be 5,950 meters at total cost of $146,905 while the estimated number of meters that would be tested in 1983 if the sample meter testing plan were adopted would be 2,890 meters at a total cost of $71,354, a savings of approximately $75,551.

3. The adoption of a sample meter testing plan will not diminish the level of accuracy of the meters or the quality of service to the consumers.

4. The adoption of a sample meter testing plan as proposed by South Kentucky is in the public interest and should be granted.

IT IS THEREFORE ORDERED that South Kentucky be and it hereby is granted permission to adopt the sample meter testing plan described in exhibit I of the application and which is attached as an Appendix to this Order.

IT IS FURTHER ORDERED that South Kentucky shall have the periodic meter testing plan on schedule before initiating the sample meter testing plan.

IT IS FURTHER ORDERED that South Kentucky shall continue to test meters in accordance with the requirements of 807 KAR 5:006, Section 19, and 807 KAR 5:041, Section 15(3).

IT IS FURTHER ORDERED that South Kentucky shall make an annual report to the Commission showing the results of the sample meter testing plan in addition to the quarterly meter test reports which are now required.

Done at Frankfort, Kentucky, this 18th day of August, 1982.

PUBLIC SERVICE COMMISSION

Marlin M. Volz
Chairman

Katherine Randall
Vice Chairman

Don Carrega
Commissioner

ATTEST:

Secretary

APPENDIX TO

CASE NO. 8536

EXHIBIT

STATISTICAL

SAMPLE TESTING PLAN FOR SINGLE PHASE

ELECTRIC METERS

SOUTH KENTUCKY RECC
SOMERSET, KENTUCKY

In considering a sample testing plan for single phase electric watt-hour meters in Kentucky, some factors other than purely statistical must be taken into account. Specifically, the requirements of the Public Service Commission rules must be integrated into the plan to insure compliance with the rules as well as to provide a plan which will be statistically sound, economical, and effective in providing the necessary standards of service to the customer.

In particular the rules state:

1) Periodic sampling plans apply only to single phase meters.
2) No meter may remain in service without testing longer than 25 years.
3) All meters must be tested at 50% power factor when tested in the shop where facilities for this test are available.
4) The overall accuracy of meters for refund and back billing purposes is obtained by averaging the percent accuracy at full load and light load.

Obviously, these and other Commission rules will have some effect on the nature of the sampling plan. i.e.:

Provision number 4: While averaging the full load (FL) and light load (LL) accuracies is permitted and valid in terms of refunding and back billing, its use exclusively in statistical evaluation of test data will obscure much information about meter performance under different load conditions. Various kinds of meters exhibit marked variations in registration particularly at light load. Therefore it is considered desirable to plot and evaluate data at full load, light load and average load.

Provision number 2: South Kentucky proposes to test as a sample* 2% of the single phase self-contained meters on active accounts in each group (not less than 50 meters). These meters will come from meters that have been on accounts in excess of 7 years.

The results of this sample would then be applied to the table (section 16 paragraph (4) (a)) to determine the number of meters in addition to the sample to be taken from those meters in each group <u>longest</u> in service (our intention is to test a minimum of 4%).

This would allow South Kentucky to test more of the meters that have been in service longest than if we pulled a 4% sample.

Example: 4% of 35,000 = 1400 meters to be drawn at random from all meters in service in excess of 7 years. 2% of 35,000 = 700 meters (sample) to be drawn at random from all meters in service in excess of 7 years with 2% (700) to be drawn from those meters in service the longest.

We feel that this plan would keep our meters in better condition due to the percentage being pulled from those in service longest.

Most sampling plans which are considered in regard to meters are based on the Gaussian or "normal" distribution. The statistics derived from the curve, i.e. $\overline{X}$ "Bar-X", and "sigma", σ once known, completely describe the curve. In other words, if $\overline{X}$ and sigma are known the curve can be reproduced. $\overline{X}$ is the arithmetic mean, and sigma is the standard deviation. The first is a measure of central tendency and the later is a measure of the dispersion of the data about the mean.

In order for these statistics to be valid and useful the population under consideration and/or the sample drawn from that population must distribute normally. For example, because σ is a mathematical function

*Sample testing will not apply to new meters. The new meters will each be tested and the test recorded by the meter test department at South Kentucky.

of the normal curve, precisely 68.26% of the items comprising the distribution will be contained in $\pm$ one σ, etc.

If the items do not distribute normally, an error or uncertainty will be introduced, the magnitude of which will depend on the degree of nonconformity of the data from the normal distribution.

If the population is homogeneous, where the quantity measured is a continuous variable and occurs randomly, and where the sample is selected randomly, the sample will distribute approximately normal, with better and better approximations as the sample size increases. But when watthour meters of different age, manufacturer, bearing systems, retarding magnets, etc., are grouped together for purposes of sample testing the group may no longer be sufficiently homogeneous to produce distributions for which $\overline{X}$ and σ are meaningful.

The experience of some utilities using sample testing has been to get multimodal, and particularly bimodal distributions. (figure 1) Also, some distributions particularly on light load tests bear no resemblance whatever to the normal curve.

The question to be answered is what is a good enough approximation of the normal distribution to justify the use of its statistics. This question must be resolved by the users of the sampling plan as the situations occur. When these situations occur the user must be aware of the limitations of the information derived, and he should attempt to determine the cause.

The sample should be drawn randomly. That is, each meter in the group should have an equal chance of being selected. <u>For a given year the sample should be without replacement. In subsequent years the sample should not include any meters which have been tested in the previous seven years.</u>

		TOTAL
FAST +	2.1	1
	2.0	
	1.9	1
	1.0	
	1.7	
	1.6	
	1.5	
	1.4	
	1.3	
	1.2	
	1.1	
	1.0	2
	.9	1
	.8	
	.7	2
	.6	4
	.5	18
	.4	21
	.3	15
	.2	16
	.1	8
	.0	3
SLOW −	.1	1
	.2	4
	.3	8
	.4	15
	.5	30
	.6	23
	.7	20
	.8	13
	.9	10
	1.0	6
	1.1	1
	1.2	2
	1.3	1
	1.4	1
	1.5	
	1.6	
	1.7	
	1.8	
	1.9	
	20	
	2.1	

TOTAL 227

Figure 1

The reliability of normal curve statistics begins to diminish at about sample size 200 (or below) and is generally considered too low at sample size 30. Consequently 30 should be the minimum sample size. Below this number other statistical techniques are employed.

In consideration of the preceeding arguments the following sample testing procedure is presented:

Steps:

1) Divide single phase meters into groups (usually five) according to differences in operating characteristics, bearing systems, compensations, etc.

2) Randomly select 2% of each group (minimum of 50). Eliminate from the sample any nonregistering meters and replace.

3) Test selected meters at LL, FL and 50% power factor when applicable (50% P.F. test will not be used in calculations).

4) Plot on separate tally sheets, FL, LL, and average of the two. (Note general shape of the distribution)

5) Compute sample mean and standard deviation for each of the above distributions.

(Perform the following operations only on the distribution for the <u>average</u> of FL and LL)

6) Standardize variables (so standard normal curve tables may be used). This is performed as follows:

The allowable error for meters is $\pm 2\%$, so $+2\%$ is the upper limit (u) and -2% is the lower limit (L). Then the standardized variables are z_u for upper and z_L for lower.

$$z_u = \frac{u - \bar{X}}{\sigma} = \frac{+2 - \bar{X}}{\sigma}$$

$$z_L = \frac{\bar{X} - L}{\sigma} = \frac{\bar{X} - (-2)}{\sigma} = \frac{\bar{X} + 2}{\sigma}$$

7) Enter table 1 page (7) with $Z = Z_U$ and read the percentage of meters faster than + 2%.

Inter table 1 again with $Z = Z_L$ and read the percentage of meters slower than -2%.

These two values are added together. They will both either be positive or zero. This is the estimate of the percentage of meters in the group outside the limits of ± 2%.

8) Refer to the table in PSC 807 KAR 5:041 E SECT. 16 ~~Elec 1 Rule XIV. 5(d)1~~ to determine if additional meters in the group must be tested. (see table 2, page 8)

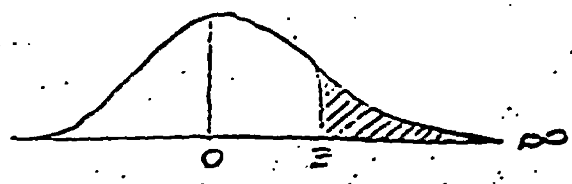
AREAS

UNDER THE

STANDARD NORMAL CURVE

from z to ∞

in percent



z	% area	z	% area
0.0	50.00	2.0	02.28
0.1	46.02	2.1	01.79
0.2	42.07	2.2	01.39
0.3	38.21	2.3	01.07
0.4	34.46	2.4	00.82
0.5	30.85	2.5	00.62
0.6	27.42	2.6	00.37
0.7	24.20	2.7	00.35
0.8	21.19	2.8	00.26
0.9	18.41	2.9	00.19
1.0	15.87	3.0	00.13
1.1	13.57	3.1	00.10
1.2	11.41	3.2	00.07
1.3	09.68	3.3	00.05
1.4	08.08	3.4	00.03
1.5	06.68	3.5	00.02
1.6	05.48	3.6	00.02
1.7	04.46	3.7	00.01
1.8	03.59	3.8	00.01
1.9	02.87	3.9	00.00

TABLE 2

Percent of Meters Within Limits of 2% Fast or Slow (Indicated by Sample)*		Percentage of Meters to be Tested Annually
99.0	100.0	2
98.0	98.9	4
97.0	97.9	6
96.0	96.9	8
95.0	95.9	10
93.0	94.9	12
91.0	92.9	14
Less than	91.0	16

* From PSC ~~[illegible]~~ 807 KAR 5:041 SECTION 16

TABLE 2

APPENDIX "I" (7 pages)

Example of Distribution Tables,

Computation of $\overline{X}$ and σ, and use

of Tables I and II.

		TOTAL
FAST +	2.1	
	2.0	
	1.9	
	1.8	
	1.7	
	1.6	
	1.5	
	1.4	
	1.3	
	1.2	
	1.1	
	1.0	
	.9	
	.8	
	.7	3
	.6	3
	.5	35
	.4	28
	.3	69
	.2	63
	.1	20
	.0	12
SLOW −	.1	28
	.2	35
	.3	96
	.4	54
	.5	101
	.6	39
	.7	41
	.8	30
	.9	11
	1.0	33
	1.1	
	1.2	1
	1.3	
	1.4	
	1.5	
	1.6	
	1.7	
	1.8	
	1.9	
	2.0	
	2.1	

TOTAL 702

SQ 35 1% SAMPLE TESTS 1968 GROUP 5

AVERAGE (X̄)
STD. DEV. (σ) = .427
NO. OF METERS = 702

METER ERROR IN % (X)	NO. OF METERS (n)	(nx)		(x^2)	(nx^2)
2.1				4.41	
2.0				4.00	
1.9				3.61	
1.8				3.24	
1.7				2.89	
1.6				2.56	
1.5				2.25	
1.4				1.96	
1.3				1.69	
1.2				1.44	
1.1				1.21	
1.0				1.00	
.9				0.81	
.8				0.64	
.7	3	2.1		0.49	1.47
.6	3	1.8		0.36	1.08
.5	33	16.5		0.25	8.25
.4	28	11.2		0.16	4.48
.3	68	20.4		0.09	6.12
.2	63	12.6		0.04	2.52
.1	70	7.0		0.01	.70
	TOTAL 2 =	67.9			
0	17		00.0	0.00	00.00
.1	29		2.9	0.01	.29
.2	35		7.0	0.04	1.40
.3	[illegible]		[illegible]	0.09	[illegible]
.4	54		21.6	0.16	8.64
.5	101		50.5	0.25	25.25
.6	39		23.4	0.36	14.04
.7	41		28.7	0.49	20.09
.8	30		24.0	0.64	19.20
.9	11		9.9	0.81	8.91
1.0	33		33.0	1.00	33.00
1.1				1.21	
1.2	1		1.2	1.44	1.44
1.3				1.69	
1.4				1.96	
1.5				2.25	
1.6				2.56	
1.7				2.89	
1.8				3.24	
1.9				3.61	
2.0				4.00	
2.1				4.41	

FAST (+) / SLOW (−)

TOTAL 1 = 702 TOTAL 3 = 230.9 TOTAL 4 = 165.60

$$\bar{X} = \frac{\text{TOTAL 2} - \text{TOTAL 3}}{\text{TOTAL 1}}$$

$$\bar{X} = \frac{(67.9) - (230.9)}{(702)}$$

$$\bar{X} = \frac{(-163.0)}{(702)} = -.232\ \%$$

$$\sigma = \sqrt{\frac{\text{TOTAL 4}}{\text{TOTAL 1}} - \bar{X}^2}$$

$$\sigma = \sqrt{\frac{(165.60)}{(702)} - (.232)^2}$$

$$\sigma = \sqrt{(.2359) - (.0538)}$$

$$\sigma = \sqrt{(.1821)} = .427\ \%$$

TALLY SHEET [illegible]

		TOTAL
FAST +	2.1	
	2.0	
	1.9	
	1.8	
	1.7	
	1.6	
	1.5	
	1.4	
	1.3	
	1.2	
	1.1	
	1.0	
	.9	
	.8	1
	.7	4
	.6	1
	.5	15
	.4	14
	.3	20
	.2	45
	.1	10
	.0	14
SLOW —	.1	40
	.2	73
	.3	50
	.4	84
	.5	139
	.6	40
	.7	64
	.8	76
	.9	2
	1.0	10
	1.1	
	1.2	
	1.3	
	1.4	
	1.5	
	1.6	
	1.7	
	1.8	
	1.9	
	2.0	
	2.1	

TOTAL 702

rm SD 55 / 1% SAMPLE TESTS 1968 GROUP 5

STD. DEV. (σ) = .357
NO. OF METERS = 702

	METER ERROR IN % (X)	NO. OF METERS (n)	(nx)	(x²)	(nx²)
FAST (+)	2.1			4.41	
	2.0			4.00	
	1.9			3.61	
	1.8			3.24	
	1.7			2.89	
	1.6			2.56	
	1.5			2.25	
	1.4			1.96	
	1.3			1.69	
	1.2			1.44	
	1.1			1.21	
	1.0			1.00	
	.9			0.81	
	.8	1	.8	0.64	.64
	.7	4	2.8	0.49	1.96
	.6	1	.6	0.36	.36
	.5	15	7.5	0.25	3.75
	.4	14	5.6	0.16	2.24
	.3	20	6.0	0.09	1.80
	.2	45	9.0	0.04	1.80
	.1	10	1.0	0.01	.10
		TOTAL 2 =	33.3		
SLOW (−)	0	141	00.0	0.00	00.00
	.1	40	4.0	0.01	.40
	.2	73	14.6	0.04	2.92
	.3	50	15.0	0.09	4.50
	.4	84	33.6	0.16	13.44
	.5	137	68.5	0.25	34.25
	.6	40	24.0	0.36	14.40
	.7	64	44.8	0.49	31.36
	.8	76	60.8	0.64	48.64
	.9	2	1.8	0.81	1.62
	1.0	10	10.0	1.00	10.00
	1.1			1.21	
	1.2			1.44	
	1.3			1.69	
	1.4			1.96	
	1.5			2.25	
	1.6			2.56	
	1.7			2.89	
	1.8			3.24	
	1.9			3.61	
	2.0			4.00	
	2.1			4.41	
	TOTAL 1 =	702	TOTAL 3: 277.1	TOTAL 4 =	174.18

$$\bar{X} = \frac{\text{TOTAL 2} - \text{TOTAL 3}}{\text{TOTAL 1}} \qquad \sigma = \sqrt{\frac{\text{TOTAL 4}}{\text{TOTAL 1}} - \bar{X}^2}$$

$$\bar{X} = \frac{(33.3) - (277.1)}{(702)} \qquad \sigma = \sqrt{\frac{(174.18)}{(702)} - (.347)^2}$$

$$\bar{X} = \frac{-244.8}{702} = -.347\,\% \qquad \sigma = \sqrt{(.2481) - (.1204)}$$

$$\sigma = \sqrt{(.1277)} = .357\,\%$$

		TOTAL
FAST +	2.1	
	2.0	
	1.9	
	1.8	
	1.7	
	1.6	
	1.5	
	1.4	
	1.3	
	1.2	
	1.1	
	1.0	
	.9	
	.8	
	.7	
	.6	3
	.5	5
	.4	10
	.3	18
	.2	35
	.1	24
	.0	48
SLOW −	.1	79
	.2	70
	.3	49
	.4	78
	.5	87
	.6	89
	.7	70
	.8	20
	.9	14
	1.0	3
	1.1	
	1.2	
	1.3	
	1.4	
	1.5	
	1.6	
	1.7	
	1.8	
	1.9	
	2.0	
	2.1	

TOTAL 702

Form SD 35 1% SAMPLE TESTS 1968 GROUP 5

AVERAGE ($\bar{X}$) = -.316
STD. DEV. (σ) = .322
NO. OF METERS = 702

	METER ERROR IN % (X)	NO. OF METERS (n)	(nx)		(x^2)	(nx^2)
FAST (+)	2.1				4.41	
	2.0				4.00	
	1.9				3.61	
	1.8				3.24	
	1.7				2.89	
	1.6				2.56	
	1.5				2.25	
	1.4				1.96	
	1.3				1.69	
	1.2				1.44	
	1.1				1.21	
	1.0				1.00	
	.9				0.81	
	.8				0.64	
	.7				0.49	
	.6	3	1.8		0.36	1.08
	.5	5	2.5		0.25	1.25
	.4	10	4.0		0.16	1.60
	.3	18	5.4		0.09	1.62
	.2	35	7.0		0.04	1.40
	.1	24	2.4		0.01	.24
		TOTAL 2 =	23.1			
SLOW (−)	.0	118		00.0	0.00	00.00
	.1	77		7.7	0.01	.77
	.2	70		14.0	0.04	2.80
	.3	49		14.7	0.09	4.41
	.4	78		31.2	0.16	12.48
	.5	87		43.5	0.25	21.75
	.6	89		53.4	0.36	32.04
	.7	70		49.0	0.49	34.30
	.8	20		16.0	0.64	12.80
	.9	14		12.6	0.81	11.34
	1.0	5		5.0	1.00	5.00
	1.1				1.21	
	1.2				1.44	
	1.3				1.69	
	1.4				1.96	
	1.5				2.25	
	1.6				2.56	
	1.7				2.89	
	1.8				3.24	
	1.9				3.61	
	2.0				4.00	
	2.1				4.41	

TOTAL 1 = 702 TOTAL 3: 245.3 TOTAL 4 = 142.90

$$\bar{X} = \frac{\text{TOTAL 2} - \text{TOTAL 3}}{\text{TOTAL 1}} \qquad \sigma = \sqrt{\frac{\text{TOTAL 4}}{\text{TOTAL 1}} - \bar{X}^2}$$

$$\bar{X} = \frac{(23.1) - (245.3)}{(702)} \qquad \sigma = \sqrt{\frac{(142.90)}{(702)} - (-.316)^2}$$

$$\bar{X} = \frac{(-222.2)}{(702)} = -.316\ \% \qquad \sigma = \sqrt{(.2035) - (.0999)}$$

$$\sigma = \sqrt{(.1036)} = .322\ \%$$

Use of Tables I and II

From the computations for average load, from the previous page.

$\overline{X} = -.316 \cong -.32$

$\sigma = .322 \cong .32$

Standardize variables:

$$Z_u = \frac{+2-(-.32)}{.32} = \frac{2.32}{.32} = 7.25 \cong 7.2$$

$$Z_L = \frac{-.32+2}{.32} = \frac{1.68}{.32} = 5.25 \cong 5.2$$

(round off using standard round of rule, or interpolate)

Enter table I with $Z = 7.2$. Table only extends to $Z = 3.9$, so value for $Z = 7.2$ is zero.

The same is true for $Z = 5.2$. Consequently all meters are within the limits of ±2% and no additional meters must be tested.

Suppose Z_u had been 1.4

and Z_L had been 1.7

Then from Table I, the value for $Z_u = 8.08\%$

$Z_L = 4.46\%$

Adding these gives a total of 12.54%. Going to Table II it is seen that 16% of the meters in the group must be tested.

APPENDIX II

Method of Computing Confidence

Intervals for $\overline{X}$ and σ

(two pages)

CONFIDENCE INTERVALS

Since the $\overline{X}$ and σ of a sample which is drawn from a population are seldom exactly the same as the mean and standard deviation of the population, it is very helpful to be able to apply some test to determine how much in error they are likely to be.

This can be achieved by means of confidence intervals. The confidence interval provides a range of values within which you have a certain probability (confidence level) that the true population statistics will lie.

Any confidence level for the confidence interval may be computed, but the 95% confidence level is very frequently used. For a 95% confidence level, the confidence intervals for $\overline{X}$ and σ are found from the following formulas:

$$\overline{X} \pm 1.96 \frac{\sigma}{\sqrt{N}} \qquad \sigma \pm 1.96 \frac{\sigma}{\sqrt{2N}}$$

Where N is the sample size.

Using a confidence interval only slightly larger, 95.44% instead of 95%, permits the use of a factor of 2 instead of 1.96 in the above formulas, thus simplifying the math.

Then:

for a 95.443 $\cong$ 95% confidence interval for $\overline{X}$ and σ, the equations

become: $$\overline{X} \pm 2\frac{\sigma}{\sqrt{N}} \qquad \sigma \pm 2\frac{\sigma}{\sqrt{2N}}$$

Example: N = 100

X = .25

σ = .30

$$\overline{X} \pm 2\frac{\sigma}{\sqrt{N}} = .25 \pm 2\frac{.30}{\sqrt{100}}$$

$$= .25 \pm \frac{.60}{10} = .25 \pm .06$$

Which means that you can be approximately 95% sure that the true population mean is between .19 and .31.

$$\sigma \pm 2\frac{\sigma}{\sqrt{2N}} = .30 \pm 2\frac{.30}{\sqrt{200}} = .30 \pm \frac{.60}{14.14}$$

$$= .30 \pm .04$$

Which means that you can be approximately 95% sure that the true population standard deviation is between .26 and .34.